connection the work of Neelakantaswamy and Ramakrishnan indicates that radiofrequency radiation can induce bending moments and stresses in the eye tissue that may provide an explanation for cataract formation. This is the same mechanism that may cause shear-strain injury in the brain (see above).

Similar compromise of the placental barrier may be expected (Frey 1988) but experiments have not yet been done in this area at low power densities.

Calcium efflux. As another way of measuring neurological response, it has been found that calcium ion efflux from brain tissue is exquisitely sensitive to irradiation with radiofrequency waves. This work has been done by Bawin et al. (1970), Blackman et al. (1980, 1986), Dutta et al. (1986) and Kunjilwar and Behari (1993), among others. See Frey (1988) for a review. In the most sensitive study to date, Dutta et al., at the Howard University Cancer Research Center, observed peaks in calcium efflux from human neuroblastoma cells at a specific absorption rate (SAR) of 1 and 2 mW/g, and also at .05, .0028, .001, .0007, and .0005 mW/g, with some effect all the way down to .0001 mW/g. The frequency was 915 MHz. This was obviously a resonance phenomenon that did not depend linearly on the dose. Peaks in calcium efflux and influx were observed at very specific combinations of modulation frequency, depth of modulation, power density, and exposure time. For example a 30 minute exposure at 80% depth amplitude modulation of 16Hz caused an efflux that did not return to normal levels for at least 20 minutes after the exposure ended. The effect at 0.0007 mW/g SAR was quadruple the effect at 2.0 mW/g, in other words 3000 times the intensity had 4 times less of an effect under these particular conditions.

Blackman (1986) also observed that varying the direction or the intensity of the local geomagnetic field also changed

the results completely. Therefore, "(1) a complete description of electromagnetic exposure conditions should include measures of frequency and intensity of electromagnetic field and direction and intensity of the local geomagnetic field; and (2) the complex interplay between frequency, intensity, and local geomagnetic field indicates that the underlying mechanism is not thermally based" (p. 44). In other words, (1) the functioning of a living organism is guided by the state of its environment; (2) perception of its environment is electromagnetic in nature; and (3) both perception and functioning are easily altered by external electromagnetic signals which, as we have seen, are some one billion times as powerful as what naturally exists.

Hypoxia. A common theme throughout the animal studies on microwave influence is a serious disturbance in carbohydrate metabolism. In particular, microwaves inhibit cytochrome oxidase activity in the mitochondria of the brain and the liver. The result is a breakdown in oxidative phosphorylation, compensatory intensification of glycolysis, and a buildup of lactic acid in the tissues. The liver becomes depleted of glycogen, the blood sugar curve is affected, and the fasting blood glucose is raised. The patient craves carbohydrates, and the cells become oxygen starved.

It may be noted that hypoxia is also a common side effect of closed head injury, and that the primary cardiac response to hypoxia is a reflex bradycardia. Hypoxia also causes demyelination in the nervous system. Oxygen deprivation may well account for many of the symptoms of radiation sickness, including fatigue, weakness, headache, inability to think, acrocyanosis, muscular pain, and, of course, shortness of breath.

Possibly additional insight into electrical injury might be had from studying the mitochondrial myopathies.

Heavy metals. It is known that chronic irradiation by microwaves causes a substantial redistribution of metals in the body and a consequent alteration in the activity of metalloproteins and metalloenzymes. For example, an increase in the activity of cerulloplasmin (a copper-containing globulin) and a decrease in the iron content of transferrin in the blood serum have been observed (Dumanskiy et al. 1982a,b). The lowered activity of cytochrome oxidase, a copper-containing hemoprotein, noted above, may also be relevant.

Shutenko et al. (1981) did a detailed study of the effect of radio waves on metals in the body, using 90 young and mature white rats and a generator of 2375 MHz (12.6 cm) waves. Intensities of 100 uW/cm^2 and 10 uW/cm^2 were both effective in redistributing metals. The animals were exposed for 2 hours a day over a period of 10 weeks. There was an increase in copper content of the lungs, brain, myocardium, and skeletal muscles, and a decrease in the liver and kidneys. There was an increase in iron content of the kidneys, lungs, myocardium, and liver, and a decrease in the spleen, brain, skeletal muscles, bones, skin and blood. Manganese content was elevated in the liver, spleen, skin, and kidneys, diminished in the myocardium, bones, and blood of young animals, and elevated in the blood of mature ones. Molybdenum content was lowered in the liver, brain, and myocardium, and raised in the blood of young animals. Most of these changes were substantial, for example copper more than doubled in the brain and decreased by more than half in the liver at 100 uW/cm^2; iron content doubled in the myocardium of young animals at 10 uW/cm^2.

Porphyria. In this context porphyria should be mentioned, because it is a disease in which metals are not handled normally by the body, and it is evidently present in many cases of electrical sensitivity (Crumpler 1996, Firstenberg 1996, Hanson 1996, Kauppi 1996).

Porphyria manifests with a wide variety of neurological signs and symptoms reminiscent of those described for electrical sensitivity/radiation sickness. It is caused by a decrease in the activity of one or more enzymes involved in the synthesis of heme from porphyrins, and may be associated with a deficiency of heme in the affected tissues. This is consistent with the decreased activity of cytochrome oxidase, a copper-containing hemoprotein, observed in microwave exposure as noted previously.

It is possible that the 2% of the population who carry the genetic trait for certain types of porphyria are predisposed to becoming electrically sensitive if they are injured by electromagnetic radiation. Research badly needs to be done in this area.

Molecular interactions. As noted above, heating by microwaves is only a secondary effect of the vibration of molecules and ions by the alternating electromagnetic field. The primary influence of the waves is on the mobility of ions and the movement, orientation, polarization and configuration of large molecules (Gabovich et al. 1979).

Muth in 1927 was the first to observe the formation of chains of emulsified fat particles in 20 kHz to 2 MHz electromagnetic fields. This is now a well-known phenomenon and is called the pearl chain effect. It occurs at all microwave frequencies and was captured on film by Liebesny and Pace in 1937, using milk, blood and yeast suspensions (Krasny-Ergen 1940, Liebesny 1938). Teixeira-Pinto et al. demonstrated chain formation in iron filings, starch

particles, colloidal carbon particles, homogenized milk, oil suspensions in water, and colloidal polystyrene spheres, and they even constrained unicellular organisms to line up in a pulsed field of approximately 25 mW/cm^2. Each type of particle, they found, has particular frequencies where the effect occurs at minimum voltage (Teixeira-Pinto 1960).

I have seen numerous assertions in the recent literature to the effect that the pearl chain effect cannot occur at non-thermal intensities, but as far as I can tell these assertions are not based on any actual experiments, and fly in the face of the fact that thermal agitation will break up the pearl chains (Copson 1962). Back in the 1930s Krasny-Ergen demonstrated that the minimum field strength for pearl chain formation in the case of red blood cells is of the order of magnitude of 0.1 V/cm (Krasny-Ergen 1940, p. 364). This is equivalent to a power density of only about 26 uW/cm^2, eminently "non-thermal" and considerably below current safety guidelines. And lest anyone consider this not a hazard, consider what it must do to the viscosity of the blood and the functioning of red and white blood cells to force them to all line up in chains.

In 1938 Liebesny wrote, "Although I will not assert on the strength of the above mentioned investigations that the non-thermic effects of the ultrashort wave field are fully explained, I venture to express the hope that those authors who are now of opinion that high frequency currents in general and short waves in particular can be biologically effective only by means of their heat effects, will modify their conclusion" (Liebesny 1938, p. 738). I trust that six more decades of research, as reviewed here, will at last put that absurd and meaningless argument to its final rest.

The pearl chain effect does have a definite power threshold. Other direct effects of electromagnetic energy

do not, or the threshold is enormously lower if there is one. Direct effects on calcium, potassium, sodium, and chloride ions, and on protein and lipid molecules alter the permeability of cell membranes and the functioning of enzymes. Frey (1992) provides an excellent review of both theoretical and experimental results in this area, as does French (1996). Gordon et al. (1974) mentions molecular resonance absorption, as do Gabovich et al. (1979) and Inglis (1970). Tofani et al. (1986) notes that a biological system can store energy from electric vibrations and that therefore the effects are cumulative. Arber (1986) reports a change in potassium conductance and water permeability across muscle cell membranes when exposed to 500 uW/cm^2, 2.88 GHz, and reviews similar work by other researchers. Mickey (1963) states that proteins can change their conformation and even be denatured under the influence of non-thermal intensities of pulsed radiation, provided the peak power is high and the average power low.

Akoyev (1980) provides a good review of molecular and ionic phenomena and also mentions the alteration of bound water. The importance of water as a mediator of microwave influence may be widely underestimated, as shown by a pair of experiments done recently (Geletyuk et al. 1995 and Fesenko et al. 1995). These researchers found that potassium channel conductance in the membranes of cultured kidney cells was altered by exposure to 42.25 GHz waves at 100 uW/cm^2 for 20 minutes. They then repeated the experiment, but instead of irradiating the cells, they irradiated the buffer solution only, then put the cells in afterwards and got the same results. They found that the solution retained the memory of the irradiation for at least 10 to 20 minutes.

Thomas et al. have taken this one step further and shown that a chemical signal (TPA) can be transmitted by

electromagnetic radiation alone to human neutrophils to alter oxygen metabolism. "This provides evidence that molecular signals are electromagnetic in nature, and are capable of being transmitted by purely physical means" (French 1996, p. 8).

Indeed Fraser and Frey (1968) have demonstrated that living neurons themselves emit radiation of micron wavelength when stimulated. In their experiment the unmyelinated walking leg sensory nerve of the blue crab emitted 3×10^{-8} W from a 0.5 mm^2 nerve surface (for a power density of 6 uW/cm^2).

The capacity of electromagnetic waves to carry meaningful signals (such as telephone conversations) depends on a property we have not discussed until now: unlike ionizing radiation, nonionizing radiation has the property of coherence. Prof. Charles Susskind testified before Congress that it is this property which is likely to be responsible for many of its effects (Susskind 1968). This is understandable, because lasers, which are coherent, are much more hazardous than ordinary light, which is not. And it is also understandable if we think of disrupting the coherent signals which may be used for cell-to-cell communication by living organisms themselves.

Solid state physics. Which brings us back to something Allan Frey said in 1971: "One problem is the assumption that we have a good understanding of nervous system function. This assumption is wrong" (Frey 1971, p. 159). As he, and Becker (1985), and Szent-Gyorgyi (1969), and Wei (1966), and Cope, and Batteau, and Augenstein all have pointed out, an accurate understanding of how the nervous system functions will have to come from the application of the principles of solid state physics and not just solution chemistry. And after that door is opened must come the realization that

biological systems are at least as exquisitely tuned and sensitive to the electromagnetic world around us as any manufactured device.

For a complete review of this subject, see Frey (1971, 1988).

18. Conclusion.

The effects reviewed in this literature survey apply to all frequencies of radio waves and microwaves, but:

- Centimeter waves are the most lethal to test animals (Inglis 1970)
- Peak internal heating of the human head occurs at 915 MHz (Johnson and Guy 1972)
- Maximum induced transmembrane potentials occur in the UHF band (Frey 1988)
- Symptoms are reported most often from exposure in the centimeter wave band, and in pulsed fields (Klimkova-Deutschova (1974)
- Microwave workers have a greater incidence of cardiac symptoms than radiofrequency workers (Huai 1979)
- Young animals are more sensitive to microwaves than mature animals (Shutenko et al. 1981)
- Children may be expected to absorb more microwave energy than adults (Baranski 1976)

In summary, the currently proliferating cellular phone (806-947 MHz), data transmission (about 900 MHz) and PCS (1.6-2.4 GHz) pulsed wave systems, according to the best evidence, are broadcasting in precisely the range of frequencies guaranteed to harm us the most, and they will have the heaviest impact on our children. Animals, wild and domesticated, will not be exempt. Flying animals, and swimming animals as we will see, will suffer the worst.

More than one scientist has noticed that the effects of microwaves are "qualitatively similar to those of ionizing

radiation" (Goldsmith 1995, p. 47). Indeed, Dr. Charles Susskind of the University of California, Berkeley, in testimony before the Senate Commerce Committee in 1968, predicted, "Although ionizing radiation seems to loom larger as a hazard, it would not surprise me in the least if nonionizing radiation were ultimately to prove a bigger and more vexing problem" (Susskind 1968, p. 720).

Letavet and Gordon said in 1960, "The harmful action of UHF on the human organism, if the intensity of the emission exceeds definite levels, has been indisputably demonstrated" (p. iv). Bigu Del Blanco said it again in 1973: "The interaction of RF radiation with biological systems has been extensively studied and established beyond doubt (especially in the microwave region)" (p. 54). Lerner said it again in 1984: "A growing mass of evidence has virtually ended that debate. Few now question that some such weak-field effects exist" (p. 57). Marino said it again in 1988: "It is clear to all reasonable investigators that EMFs can affect physiology" (p. 993). In the late 1990s it is past time to agree that the jury is in fact in, that it has been in for some time, and that the present proliferation of wireless technology must be stopped before it does us all irreparable harm.

Let us now look briefly at some of the other impacts that the wireless revolution is having on our atmosphere, our climate, and our biosphere as a whole.

Endangered species

The evidence from Skrunda proves that microwaves considerably less powerful than those from the average cellular tower do damage not just to human beings, but to plant and animal life as well. At Skrunda we have seen effects on trees that are similar to recent symptoms of dieback in forests all over the world, and we must conclude that acid rain may not be the main culprit. We have also seen proof of chromosomal damage in cows, which verifies considerable anecdotal evidence of large numbers of tumors and birth deformities in farm animals (and people) near cellular towers (Hawk 1996). Hawk also mentions the disappearance of honeybees in the vicinity of these towers, so it becomes relevant to speculate on the sudden nationwide disappearance of bees within the last year, simultaneous to the massive expansion of the cellular industry. It may not just be a case of parasites. And we have already discussed the expected impact on birds.

We have also speculated on the worldwide decline and extinction of amphibians, but this year there is a new phenomenon, and it complements the reports from farmers of farm animals born with webbed necks and legs on backwards after cellular towers go up (Hawk 1996). It seems that frogs throughout Minnesota, Wisconsin, South Dakota, Vermont, and southern Quebec are turning up with deformed legs, extra legs, missing legs, missing eyes, misplaced eyes, and other terrible deformities (Souder 1996, Hallowell 1996). The phenomenon may turn out to be much more widespread. Significantly, the species with the highest rates of deformities are those that spend the most time in the water. For example, in a seemingly pristine lake in Crow Wing County, Minnesota's most popular lake vacation

district, 50% of all mink frogs were deformed this year, while American toads and wood frogs, which spend the least time in the water, had deformity rates under 5%. The connection to microwaves is speculative, but it is highly educated speculation, considering that popular vacation districts are sure to have had cellular towers erected within the last year, and considering the role water is known to play in mediating the effects of microwaves (see the discussion about mechanisms, above). Many people who suffer from electrical sensitivity also report that their illness is worse on rainy or foggy days (Hawk 1996, and personal communications).

The disappearance of fish from so many pristine mountain lakes also comes to mind. Acid rain may not be the only, or in many cases the true culprit. The electrification of the world must be seriously considered, especially as the disappearance of fish has occurred at high elevations, and the dieback of forests has been observed on ridgetops, where microwave relay towers usually go.

The danger from satellites

The proliferation of satellites we are about to witness --unless this world wakes up soon--is mind boggling, and nobody seems to have considered that popping thousands of them up there like so much confetti might have consequences for our atmosphere and our climate.

And there will be thousands. Orbcomm plans a fleet of 28, of which 2 are already in orbit. Motorola plans one fleet of 72 called Iridium, at an altitude of 485 miles, of which the first 3 are due for launching imminently, and the rest within a year or so; another fleet of 72 called M-Star will fly 350 miles higher. Odyssey's fleet of 12, and Globalstar's 48, are not far behind. Neither is Teledesic, the brainchild of Bill Gates and Craig McCaw. It will need 924 satellites, to be placed in 21 orbital planes each containing 40 active satellites and 4 spares. They'll be 435 miles above us. It is billed as "a kind of a sky-based, wireless multimedia Internet" (USA Today, Sept. 26, 1996). There are also dozens, perhaps hundreds of small companies founded by small private entrepreneurs who are already sending up fleets of smaller, cheaper satellites that we never hear about. NASA facilities in California and Florida have been converted into private spaceports. Launch facilities are being built in Alaska, New Mexico, and Virginia by companies hoping "to provide space data showing where the potholes are and whether buses are on schedule, to build systems that find hikers lost in the wilderness and oil tankers on the high seas" (Millar 1996). All of this hardware is considered disposable and will need replacements every five years, so there will be a steady

stream of hundreds if not thousands of satellite launchings every year for the foreseeable future, starting now.

The hazards are real and many.

1. Microwaves on the order of 10^{-7} uW/cm^2 in power will be raining down on top of us from each one of these things, and we have already seen that this is enough to be biologically active. One of the reasons for the low orbits is to place the satellites closer to the earth so the signal is stronger and the receiving antenna doesn't have to be so big, but this makes them relatively more dangerous.

2. Rocket exhaust destroys ozone. It has been calculated that 9 Space Shuttles and 6 Titan IV launches peryear would only put enough chlorine into the stratosphere to destroy 0.1% of its ozone (Prather et al. 1990). But few people seem to be considering what hundreds or thousands of launchings will do and are doing. Aleksandr Dunayev of the Russian space agency was quoted in 1989 as saying, "About 300 launches of the shuttle each year would be a catastrophe and the ozone would be completely destroyed" (Broad 1991). He seems to have been correct, because the calculations of Prather et al. are probably an order of magnitude too low. They themselves noted that they did not take into consideration the reactions occurring on stratospheric clouds that cause the ozone holes over the poles. And they failed to consider that the use of chlorine-containing solid rocket boosters is increasing and not decreasing throughout the world. And that other components of rocket exhaust also pose a significant threat to ozone, including water vapor and particles of aluminum oxide that seed the stratospheric clouds. Rockets and space debris burning up on re-cntry also contribute such particles (Discover 1990).

3. We are also destroying the Van Allen belts, with consequences that are not entirely clear. For one thing, power lines and radio towers already broadcast enough energy into space to interact with the Van Allen radiation belts and cause an increase in the fallout of charged particles over the earth. This is probably enhancing cloud formation and increasing thunderstorm activity (Park and Helliwell 1978). The orbiting of huge fleets of mobile radio transmitters directly in the Van Allen belts is sure to enhance this effect.

Additionally, there is already so much material orbiting the earth that the high energy particles in the radiation belts are being seriously depleted by collisions with space junk (Konradi 1988).

4. Rocket exhaust also produces acid rain and massive water pollution near launch sites, and contributes further to global warming by adding water vapor to the stratosphere. These effects have been judged minor, but at the planned rate of space traffic they will not remain so.

5. The manufacture of satellites, and also hundreds of millions of cellular phones, faxes and computers will make an already polluting industry much worse. 186 different toxic chemicals are used in the manufacture of semiconductors, for example, including acids, solvents, poisonous gases, and heavy metals (NIOSH 1985). The electronics industry has become one of the largest producers of hazardous wastes and is a major polluter of groundwater all over the world.

6. The night sky will never be the same.

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